IMPACT OF SOIL CONDITION, TOPOGRAPHY AND LAND USE ON THE EROSION CHARACTERISTICS OF PHULENG-E-NYANE, HA MANTSEBO: A USLE ANALYSIS

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DECLARATION

The work contained in this dissertation was carried out and completed by Ntšolo Matšaba, 201801424 at the National University of Lesotho Water Institute. I hereby declare that this study constitutes my original work and has never been submitted for the award of a degree or diploma to any University. To the best of my knowledge this dissertation contains no material written by another person except where due reference is made in the dissertation itself.

Signature N. Matšaba **Date** 09/10/2025

As the candidate's supervisors, we certify the above statement to be correct to our knowledge and have recommended this dissertation for submission.

Prof. Makoala V. Marake………………………………………. Date: 09/10/2025

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ABSTRACT

Soil erosion is a natural yet complex process resulting in the detachment and movement of soil by agents including water and wind, often accelerated by anthropogenic activities such as agriculture and land use changes. It threatens soil fertility, agricultural productivity and ecosystem health making its assessment crucial for sustainable land management. In this study, the impact of soil erosion causing factors on the erosion characteristics of Phuleng-e-Nyane Ha-Mantšebo were evaluated using the Universal Soil Loss Equation (USLE) model. A randomized complete block design in a split plot arrangement was employed to assess soil erosion across the area. The main plot consisted of two farming systems, cropland and long-term fallow land. Within each farming system, the subplot factor was the topo-sequence position comprising four levels: summit, shoulder, back-slope and toe-slope. The soil erosion factors used to determine the total soil loss in USLE include, rainfall erosivity index, soil erodibility factor, topographic factor, crop management factor and conservation factor.

Disturbed and undisturbed soil samples were collected, whereby, the disturbed soil samples were collected using soil auger at 30 cm depth and undisturbed soil samples using the core samples. The secondary rainfall data for Moshoeshoe I International Airport was collected from the Lesotho Meteorological services while the slope length was measured using the 100 m fiberglass open reel measuring tape. Google earth was used to look at land use and land cover overtime. Correlation analysis was used to examine the relationship between soil loss and the contributing factors. The localized soil loss prediction model was developed. The total soil loss from study area was calculated at 12.25 Mg ha^{-1} yr^{-1} with cropped land contributing about 95.2% of the loss (about 53.7% from the north transect and 41.5% from the southwest transect) while 4.8% was from the long-term fallow land approximately shared equally among the two transects. The stepwise regression analysis revealed that land use is the most influencing factor on soil loss from the area, followed by topography. The study highlights the importance of integrating effective management practices to sustain soil health and reduce erosion hazards.

Key words; land use type, Lesotho, soil erosion, soil properties, USLE, Toposequence, Transect

LIST OF ACRONYMS

DEM	Digital Elevation Model
GIS	Geographical Information system
GPS	Global Positioning System
LS	Topographic Factor
LULC	Land Use, Land Cover
MUSLE	Modified Universal Soil Loss
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SL	Slope Length
USLE	Universal Soil Loss Equation

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CHAPTER ONE

INTRODUCTION

1.1. Background

Soil erosion assessment plays a critical role in understanding its impact on agricultural productivity and food security and leads to the degradation of land quality, which directly affects crop yields and consequently, food security (Terefe *et al.*, 2025). The assessment of soil erosion helps in identifying the extent and severity of erosion, enabling the implementation of effective soil management practices to mitigate its adverse effects (Senanayake *et al.*, 2020). This is particularly important in regions like Lesotho where agriculture is a primary source of livelihood and food supply.

The erosion-sedimentation cycle includes soil erosion, a form of land degradation that can be brought on by inadequate land management and made worse by climate change (Djoukbala and Hasbaia, 2019). It is a major global environmental threat to both the sustainability, productive capacity of agriculture and food security (Mullane, 2013). Sheet erosion removes soil layers while detachment of soil particles breaks soil aggregates and induces mass movement of nutrients through the soil. Soil erosion is also a major source of sediments that cause pollution and sedimentation of streams and reservoirs thereby disturbing both terrestrial and aquatic ecosystems (Quinton and Fiener, 2024). The loss of cropland due to erosion is a serious problem. According to Pimentel and Burgess (2013),“about 10 million ha of cropland are lost globally due to soil erosion annually, and reduces arable land available for world food production”.

Because soil erosion reduces the land's capacity to produce food, it poses a serious danger to global food security (Collins *et al.*, 2021). A global economic contraction of up to US$ 625 billion by 2070 is projected due to soil erosion, with primary agricultural production losses potentially reaching 352 million tons (Sartori *et al.*, 2024). Vulnerable regions, particularly in Africa and tropical areas, face acute challenges in food security due to soil erosion. These regions are at risk of experiencing significant shortages in staple crops, such as oilseeds (Sartori *et al.*, 2024). In areas like Southern Ethiopia, soil erosion has led to food insecurity among households, as the decline in agricultural productivity limits food availability (Dofee and Goshu, 2023). Since food is a basic human need, conserving cropland and maintaining soil fertility should be a global priority.

Although soil erosion is an intercontinental problem, Africa is the most hit and vulnerable continent (Mekuria *et al.*, 2024) and associated with issues of food insecurity in sub-Saharan nations, particularly on marginal areas where the topography is often steep and the soil quality is low. Effectively, soil erosion results in the removal of the nutrient-rich topsoil (Djoukbala and Hasbaia, 2019), which is essential for crop growth. Land productivity and soil fertility suffer as a result of this loss. Studies showed that in southern Ethiopia, over 91% of households reported decreased land productivity due to soil erosion (Dofee and Goshu, 2023). Similarly, in Nepal, soil erosion reportedly led to a reduction in cropped area and a decrease in productivity by 0.238 t ha^{-1} yr^{-1}, highlighting the direct impact on agricultural output (Bhandari *et al.*, 2021). This can be attributed to depletion of essential nutrients e.g. Nitrogen and Phosphorus, which are crucial for plant growth. This nutrient loss further exacerbates the decline in agricultural productivity (Rashmi *et al.*, 2022).

Smallholder farmers in particular dominate the cropping landscape raising row crops such as maize (*Zea mays*) and beans (*Phaseolus vulgaris*) which are highly susceptible to erosion as they do not cover the entire tilled soil surface (Pimentel and Burgess, 2013). The foregoing is worsened by conventional tillage and monoculture practices on steep slopes leading to accelerated soil erosion compounded by erodible nature of soils, unsustainable management practices, climate change impacts leading to severe droughts, floods, storms and wildfires which incidentally constitute major drivers for soil erosion (State of the Climate in Afric*a*, 2023). Erosion is the most common driver of land degradation occurring when soil is moved from the higher topographic areas and deposited in downslope positions on the landscape by water (Boardman, 2000; Makara, 2013) and currently it is a critical environmental hazard in Lesotho (Moeletsi and Walker, 2013). It is estimated that the country loses upwards of 40 million tons of soil per year through gully, sheet, and rill erosion (Moeketsi and Walker, 2013). Geological erosion in Lesotho is accelerated by overgrazing, poor farming practices, unstable roads construction and management practices (Chakela, 1981; Makara, 2013).

Soil condition is the current state of soil, which is characterized by its dynamic attributes influenced by land management practices, environmental factors and soil properties. These properties include physical (e.g. texture, structure and bulk density), chemical (e.g. nutrients content, soil organic matter and soil pH) and biological (e.g. microbial activity) characteristics that collectively impact soil health, fertility, structure and its ability to support plant growth.

Depending on the local soil and climate, soil properties may help reduce nutrients losses, control weeds, increase infiltration and increase the volume of water retained in soil profile, which may lead to greater soil erosion and drought resilience (Çerçioğlu *et al.*, 2025).
Soil erosion, with the resultant pressure on arable land, compounded by negative impacts of climate change makes it clear that new management techniques are required to reduce soil loss (Geekiyanage *et al.,* 2025). Thus, it is appropriate to apply GIS technology to support soil erosion inventory in relation to soil erosion modeling and erosion hazard assessment (Jazouli *et al.,* 2017). Across many ecosystems, similar data sets from long-term soil erosion monitoring should be used in management techniques (Smetanová *et al.*, 2018). To effectively control soil erosion in areas with high precipitation, it is necessary to comprehend the interannual fluctuations in sediment output at the regional level (Smetanová *et al.*, 2018)

1.2. Problem Statement

The impacts of soil condition, topography, and land use on soil erosion characteristics in Lesotho are multifaceted and significant. Lesotho's landscape, characterized by its mountainous terrain and variable land use practices, is highly susceptible to soil erosion, which has profound implications for agriculture, water quality, and environmental sustainability (Liu *et al.*, 2025). The interplay between these factors determines the severity and distribution of soil erosion across the region (Chakrabortty *et al.*, 2025). Thus, the current severity of soil erosion in Lesotho is exacerbated by topography and land use changes resulting in significant soil loss, with billions of tons of fertile soil washed away annually.

Soil erosion in Lesotho presents significant environmental challenges, characterized by severe sheet and gully erosion resulting in land degradation that has transformed the landscape and impacted agricultural productivity. Despite a long history of conservation efforts and research studies, the problem persists under a combination of natural and anthropogenic factors including presence of dispersible duplex soils which are susceptible to gully formation, steep slopes, climate and poor agricultural practices. Also soil erodibility plays a crucial role in erosion dynamics (van Zijl *et al.,* 2013).

The current state of soil erosion in Lesotho is detrimental to agricultural productivity. In particular, it results in the loss of fertile topsoil, leading to decreased agricultural yields and increased food insecurity (Makara, 2013). Furthermore, it affects water quality and reservoir capacity because it contributes to sedimentation in rivers and siltation of reservoirs, complicating water treatment processes and affecting aquatic ecosystems (Jazouli *et al.,* 2017). Thus, the economic consequences of soil erosion are severe. Significant social and economic costs are incurred by the nation as a result of land degradation, which reduces the provision of ecosystem services in a variety of ways, including declining food availability, soil fertility, carbon sequestration capacity, timber output, groundwater recharge, etc. (Rhodes, 2014). The annual cost of land degradation in Lesotho is estimated at 57 million United States dollars (USD) equivalent to 3.6% of the country's Gross Domestic Product (Global Mechanism of the UNCCD, 2018). Environmental consequences entail the silting of water bodies, loss of soil fertility, and degradation of ecosystems while in socio-economic terms, erosion can impoverish rural communities, leading to rural exodus and loss of agricultural productivity (Neto *et al.*, 2023).

Researchers have analyzed the impacts of topography and land use on soil erosion rates in agricultural catchments (Sonya, 2020). They highlight that soil condition, topography, and land use significantly impact soil erosion characteristics. They underscore the significance of factors such as slope length, topographic factor, and topographic wetness index. In Lesotho, similar conditions may lead to varying soil erosion characteristics influenced by steep terrain and land use practices. Thus, developing efficient conservation and soil erosion management plans suited to Lesotho's particular topography and land use circumstances requires an awareness of these linkages (Firoozi and Firoozi, 2024). This study aimed at investigating the effects of soil condition, topography, and land use practices on soil erosion characteristics in Lesotho.

1.3. Justification of the Study

Studying the impact of soil conditions, topography, and land use in Lesotho is crucial due to the severe soil erosion that significantly affects agricultural productivity and environmental sustainability. The unique topographic features and climatic conditions of Lesotho contribute to high erosion rates, necessitating a comprehensive understanding of these factors to inform effective land management practices. Soil erodibility varies across the mapping units of the soils of Lesotho (Chakela and Stocking, 1988) with certain soil types, such as dispersible duplex soils, being more susceptible to erosion (Zijl *et al.*, 2013). The Revised Universal Soil Loss Equation model indicates “substantial annual soil loss in excess of 26 million tons in 2009, highlighting the urgent need for soil conservation strategies” (Makara, 2013). The steep slopes and varied topography of Lesotho exacerbate erosion, as agricultural practices often occur on these challenging terrains (Dodson, 2006). Studies showed that contour farming, intended to reduce erosion, can inadvertently lead to gully formation when not properly managed (Dodson, 2006). Thus, erosivity factors, including rainfall intensity and duration, play a significant role in soil erosion dynamics, with varying impacts across different climatic zones in Lesotho hence understanding these interactions is essential for developing guidelines for sustainable land use and crop development in vulnerable areas (Manyevere *et al.*, 2016).

One of the most crucial factors to investigate is the rainfall erosivity component (R) of the USLE family of soil erosion models, which is greatly impacted by climate change. (Chen *et al.*, 2023). Thus, studying soil conditions, topography, and erosivity in Lesotho is justified to understand and model soil loss, ensuring sustainable land use and to identify land practices that minimize unacceptable erosion rates (Smith, 2000). While the focus on soil conditions and topography is critical, it is also important to consider socio-economic factors and historical land use practices that have contributed to the current state of soil erosion in Lesotho. Addressing these broader issues may provide a more holistic approach to soil conservation efforts.

1.4. General Objective

The aim of this study is to determine the quantity of soil loss from a selected watershed in relation to soil properties and soil loss factors of the USLE model.

1.5. Specific Objectives

The specific objectives of this study are:

(i) to estimate the rainfall erosivity index of the studied area

(ii) to analyze the relationship between the soil properties (e.g., texture, structure, organic matter content) and erosion rates within the watershed.

(iii) to evaluate the role of topographic factors (e.g., slope length and slope steepness) in erosion processes.

(iv) to evaluate the impact of land use practices on erosion susceptibility.

(v) to develop a localized predictive model to estimate erosion risk over time based on the integration of rainfall, soil, land use, and topographic data.

1.6 Contribution to Knowledge

Measurements of soil erosion rates specific to this agricultural watershed, factoring in variables such as soil type, land use, and topographical features will not only help in quantifying the soil erosion but also help in pinpointing areas within the agricultural watershed most susceptible to soil erosion, sedimentation, or nutrient loss. This study will also help in understanding the impact of farming methods on soil stability and erosion while giving insights into how soil properties (e.g., texture, compaction, organic content) influence runoff, infiltration, and erosion in an agricultural setting (Doctorat, 2016). The study aims at determining the influence of land cover on erosion by evaluating how different types of vegetation or crop cover mitigate or exacerbate erosion within the watershed. Lastly the study aims to identify how slope gradient and length impact water flow, sediment transport, and deposition in the agricultural context. These will assist in development of conservation strategies such as contour farming, terracing, or cover cropping and bring guidance for sustainable land use and soil conservation tailored to the watershed (Erdoğan *et al.*, 2016). These will provide a clear direction and contribute to both theoretical insights and practical solutions for managing agricultural watersheds.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Nature of Soil Erosion Processes

Soil erosion processes are complex phenomena influenced by both natural forces and human activities. These processes can be categorized into various types, primarily driven by water, wind, and gravity. In general, widespread and strong winds, little vegetation, loose, dry, finely divided soil, and a smooth soil surface all contribute to erosion (Hagen and Foster, 1990). while water erosion is increased by the fore mentioned factors together with intense rainstorms (Hagen and Foster, 1990). Understanding these processes "is crucial for sustainable land management and mitigating environmental impacts (Moisa, 2020). Among the several classification systems of erosion phenomena, categorizing erosion into natural erosion and accelerated erosion is very important. Anthropogenic activities have led to a significant, degradation of the soil cover, which manifest in the decrease and destruction of its production potential compared to natural conditions (Aliyev, 2022).

2.1.1 Water erosion

Agricultural and natural landscapes are greatly impacted by water erosion processes, which are crucial phenomena that include the detachment and movement of soil particles by water (Batista *et al.*, 2019). These processes can be categorized into several types, each with distinct mechanisms and implications for soil health and management (Abawa *et al.*, 2024). Understanding these processes is essential for developing effective erosion control strategies (Firoozi and Firoozi, 2024). This includes raindrop detachment, inter-rill erosion, rill erosion, and gully erosion, where water flow detaches and transports soil particles. Raindrop detachment is initiated by the impact of raindrops leading to splash erosion and shallow flow transport, commonly referred to as inter-rill erosion (Flanagan, 2024). This is followed by development of rill erosion which occurs in small channels formed by concentrated flow involving head-cut formation and sediment transport. Rills then develop into ephemeral gully erosion which evolves into larger channels that form during heavy rainfall, characterized by significant sediment transport and deposition. Rainfall characteristics are frequently the subject of research in many studies because it is the main factor that causes soil erosion by water (Borrelli *et al.*, 2021; Carollo *et al.*, 2017; Panagos *et al.*, 2015). In the Universal Soil Loss Equation (USLE)-type soil erosion models (Renard *et al.*, 1997; Wischmeier and Smith, 1965, 1978), the impact of this driver is described by the rainfall and runoff factor (R), often called the rainfall erosivity parameter, or R factor (Alewell *et al.*, 2019; Nearing *et al.*, 2017).

However, a number of factors influence water erosion processes which affect erosion rates including soil texture, structure, and soil water content (Blanco-Canqui and Lal, 2023). In addition, vegetative cover can mitigate erosion by stabilizing soil and reducing runoff (Blanco-Canqui and Lal, 2023). The foregoing is compounded by anthropogenic activities which exacerbate erosion, particularly through soil trampling and land use changes (Lima *et al.*, 2024). While water erosion can lead to soil formation and nutrient redistribution, excessive erosion can result in severe environmental degradation, necessitating careful management practices to balance these effects (Blanco-Canqui and Lal, 2023).

2.1.2 Wind erosion

Wind erosion is a complex process influenced by various environmental and anthropogenic factors (Tola, 2019). Soil particles are separated and moved by wind forces, influenced by factors such as velocity, precipitation, surface roughness, soil texture, vegetation cover, and human activities on the landscape (Skidmore, 2017). It involves “the detachment and movement of soil particles by wind” energy, primarily occurring under conditions where soil is loose, dry, and lacks vegetation cover (Blanco-Canqui and Lal, 2023). In arid and semi-arid environments, wind can lift and carry soil particles (Borrelli *et al.*, 2024). Wind erosion processes are a function of particle dynamics and involve three primary mechanisms: “suspension, saltation, and surface creep. Suspension refers to fine particles lifted into the air, while saltation involves particles bouncing along the surface, and surface creep describes larger particles rolling or sliding” (Lyles, 1988). Specifically, wind erosion processes include “initiation, transport (suspension, saltation, surface creep), abrasion, sorting, avalanching, and deposition of soil aggregated particles” (Lyles *et al.*, 2015). These processes alter surface-soil properties and size distributions, impacting crop productivity through changes in soil depth and nutrient availability.

Control strategies include maintaining vegetative cover, promoting formation of non-erodible soil aggregates, and reducing field width along prevailing wind directions to mitigate erosion effects. However, wind erosion processes are conditional to certain thresholds being exceeded. For example, wind erosion occurs when wind speeds exceed a variable threshold dependent on "soil texture and soil water content" (Blanco-Canqui and Lal, 2023; Lyles *et al.*, 2015). Soil properties are critical factors influencing wind erosion. For example, loose, dry, and finely granulated soils are more susceptible to erosion while soil texture and aggregation play significant roles in determining erosion rates (Blanco-Canqui and Lal, 2023; Lyles *et al.*, 2015). Vegetative properties and surface roughness similarly affect wind erosion processes. For example, sparse vegetation and smooth surfaces increase vulnerability to wind erosion and vegetative cover can significantly reduce erosion by trapping soil particles (Hagen, 2002; Lyles *et al.*, 2015). However, wind erosion processes involve the detachment and transport of soil particles influenced by wind-driven rain (Widiatmika, 2015a). Research highlights the significance of wind velocity and direction on sediment transport, rain splash detachment, and the interactions between wind and rain during erosion events (Erpul, 2016).

Effective management requires understanding the dynamics of wind erosion to design appropriate control measures. This includes optimizing land management practices to minimize soil loss and mitigate offsite impacts, such as air quality issues and sediment transport (Hagen, 2002; Hagen, 1991). While wind erosion poses significant challenges, it is essential to consider the potential benefits of certain land management practices that may inadvertently enhance soil stability and reduce erosion (Abawa *et al.*, 2024). For instance, strategic biological practices e.g. grass or tree planting can improve soil structure and resilience against erosive forces.

2.2 Geological (Natural) Erosion Phenomena

This type of erosion is known as natural or normal erosion as it occurs in nature overtime without any human influence. Geological erosion has contributed to the formation of our soils and their distribution on earth. The process occurs when the soil erodes from the land surface by any of the aforementioned erosion agents glacial movement sculpturing most of the present day topographic features like stream channels and valleys over time (Kumar Sharwan, 2020). Under natural undisturbed conditions, an equilibrium is established between the driving and resisting forces influenced by climatic variables (Ginocchio, 2006). For example, vegetative cover, grasslands and forests, retard the transportation of soil material and act as a check against excessive erosion (Wagner and Frevert, 1955).

2.2.1 Topography

The physical features of the land also contribute to soil erosion. Higher slopes facilitate the faster movement of water downstream. Among the topographic elements that have the biggest effects on soil erosion is slope gradient. It can alter the kinetic energy of erosion by controlling the angle at which raindrops splash, increasing the potential for erosion. According to She *et al.* (2020), many studies have indicated that soil erosion was directly proportional to the slope gradient, and that there was a critical slope gradient at which the soil erosion rate was maximal.

Topography also has a major impact on the processes of soil erosion, by virtue of its authority over slope length, steepness, and the spatial distribution of soil properties (Kobusinge *et al.*, 2023). The concept of a topo-sequence/topographical sequence-a lateral succession of soils along a slope shaped by topographic variation-provides a valuable framework for understanding how soil characteristics and erosion risk change with position on the landscape. Originally defined as a continuum of soil profiles aligned along a topographic gradient, topo-sequence reflect variations in soil depth, texture, organic matter, and moisture retention that result from differential erosion, deposition, and soil formation processes at distinct slope positions. This variability is critical in the Universal Soil Loss Equation (USLE), as factors such as slope length and steepness (LS factor) and cover-management (C factor) vary systematically along a topo-sequence (Ruhe, 1969), influencing the magnitude and pattern of soil loss. Figure *1* depicts a typical arrangement of topographic position on a topo-sequence.

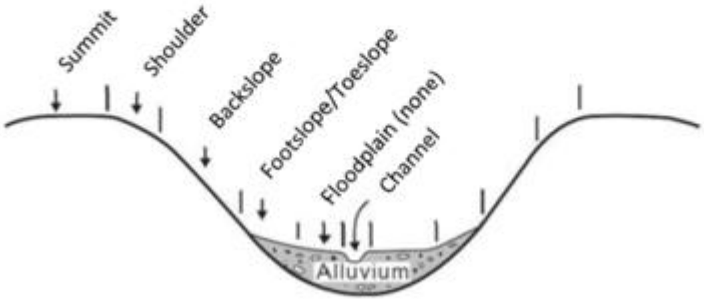

Figure 1: the typical arrangement of topographic position on a topo-sequence (Source: Ruhe, 1969)

Thus, incorporating the topo-sequence concept into soil erosion studies allows for a more nuanced assessment of erosion potential across the landscape, improving the accuracy of USLE predictions and informing targeted soil conservation practices tailored to specific slope positions.

2.2.2 Rainfall and flooding

Rainfall and flooding influence both the rate and severity of soil loss. Rainfall acts as the primary driver of soil erosion by detaching soil particles and generating surface runoff that transports sediments downslope (Nearing *et al.*, 2017). The intensity, duration and pattern of rainfall critically determine the erosion processes. High intensity rainfall, especially short-duration storms, produce strong raindrop impact and rapid surface runoff, which can cause significant soil detachment and transport, leading to accelerated erosion rates. Flooding exacerbates soil erosion by increasing the volume and velocity of surface water flow (Pragna *et al.*, 2023). Floodwaters can erode large amounts of topsoil, especially on slopes by enhancing the hydraulic force acting on soil surface. This process not only takes away fertile soil erosion but also transports nutrients and organic matter, reducing soil fertility and agricultural productivity (Kobusinge *et al.*, 2023). It also causes soil crusting and sealing which decreases infiltration, further increasing runoff and erosion potential.

2.3 Accelerated or Human-induced Erosion Phenomena

Accelerated soil erosion processes are significantly influenced by direct or indirect anthropogenic factors leading to detrimental impacts on soil health and ecosystem services. These processes are often exacerbated by intense rainfall events, land use changes, and poor management practices, which can create a feedback loop that further accelerates erosion (Panagos, 2015). Changes in land use and habitation brought on by human activities and exacerbated by weather conditions can contribute to erosion. Reduced fertility and greater soil loss are the results of these processes (Aliyev, 2022). Among the anthropogenic factors that contribute to the development of erosion are vegetation removal in the form of overgrazing, deforestation. In addition, infrastructure development, such as “roads or other obstacles on arable land that encourage the buildup of surface runoff, hydrological changes in rural and urban areas, animal or human trails, retention basin overflow, mining operations, or other interventions that concentrate surface” flow water can all have an impact on accelerated erosion (Kuhn *et al.*, 2023).

2.3.1 Climate change

Accelerated soil erosion and CO_2 emissions are interconnected, with each influencing the other, creating a feedback loop. For example, climate change significantly impacts soil organic carbon (SOC) dynamics, leading to increased greenhouse gas emissions and affecting soil health and ecosystem functions (Lal, 2019). On the other hand, soil erosion rates may be expected to change in response to changes in climate for a variety of reasons including changes in the erosive power of rainfall (She *et al.*, 2020). According to (Nearing *et al.*, 2005), changes in plant biomass are the second main way that climate change affects erosion rates. As anthropogenic activities increase atmospheric carbon dioxide concentrations, plant production rates and changes in plant transpiration rates increases, which means an increase in soil surface cover (Nearing *et al.*, 2005). Key drivers of accelerated soil erosion include intense rainfall events. For instance, increased rainfall intensity contributes to water erosion, particularly in vulnerable catchments, leading to significant soil degradation.

2.3.2 Soil conditions

Soil conditions significantly influence the accuracy of erosion modeling across various landscapes, as they determine the interaction between soil particles and erosive forces such as water and wind. Different soil properties, such as texture, structure, and organic matter content, affect soil erodibility and the subsequent modeling of erosion processes(Rajesh, 2023). The accuracy of erosion models is also contingent on the landscape's geomorphological and climatic conditions, which can vary widely across different regions.

In erosion models like RUSLE, soil erodibility is a crucial parameter that measures how easily soil particles can be detached and carried by surface runoff and rainfall (Achite *et al.*, 2025). The K factor can vary significantly depending on the soil's texture and organic matter level, affecting model predictions (Degife *et al.*, 2021). For instance, a study using sequential Gaussian simulation highlighted the importance of accurately estimating soil erodibility to improve model reliability (Jamshidi *et al.*, 2014). Studies have shown that soil water content and surface roughness significantly influence erosion rates. For example, subsurface soil water pressure can alter sediment concentration in runoff, impacting model accuracy (Römkens *et al.*, 2002)

Different soil conditions significantly impact erosion modeling accuracy by influencing sediment yield and runoff dynamics. For example, surface roughness, slope steepness, and antecedent soil moisture conditions affect soil loss and sediment concentration (Romkens *et al.*, 2002). They further showed that smooth surfaces generally yield less soil loss compared to rough surfaces, while subsurface soil water pressures can alter sediment concentration without affecting runoff volume. These variations necessitate the development of process-based models that account for the complex interactions of these factors across diverse landscapes.

The soil's physical, chemical, and biological characteristics are very important is soil erosion assessments (Kobusinge *et al.*, 2023). Among the severe soil degradation circumstances that might hasten the process of soil erosion include soil compaction, insufficient organic matter, loss of soil structure, inadequate internal drainage, salinization, and issues with soil acidity (McKague, 2024).

2.3.3 Land use and land cover

These are two related but distinct terms used in environmental science, geography and land management. The term "land cover" describes the physical materials that make up the earth's surface, whereas "land use" describes how people use land or what activities they do with it (Krishnakumar, 2025). Their importance lies in their profound impact on environmental sustainability and resources management. Changes in land cover driven by land use decisions affect ecosystem services such as water regulation, climate moderation and biodiversity conservation (Vadrevu *et al.*, 2025).

The term "land cover" describes the physical materials that make up the surface of the earth, whereas "land usage" describes how people use land or what activities they do with it. Given that farmlands are more susceptible to wind and rainfall, natural vegetation offers significantly superior protection than crops. Because agricultural activities reduce biodiversity in soil microbes and flora variety, they can lead to soil erosion. Field fertility is impacted by a lack of organic matter and beneficial biota because bare fields lose nutrients in addition to earth particles (EOS DATA ANALYTICS, 2024). In developing countries such as Lesotho, loss of vegetative cover is common due to growing populations and inadequate agricultural practices that fail to protect the top soils (Pimentel and Burgess, 2013). This can be because plant residues are often used for heating and cooking.

2.4 Methods of Soil Erosion Assessments

Successful erosion assessment depends on estimating the risk of soil loss and its spatial distribution (Parveen and Kumar, 2012). Researchers have created a number of predictive models for soil erosion evaluations that calculate soil loss and pinpoint regions where conservation efforts will have the biggest influence on lowering soil loss. Despite development of varies models, Universal Soil Loss Models are the most popular empirically based models used globally for erosion prediction and control and has been tested in many agricultural watersheds in the world"(Parveen and Kumar, 2012). According to Parveen and Kumar (2012), their simplicity, which enables them to be used even with sparse data, is the primary factor for their widespread usage in soil erosion and sediment yield estimates.

2.4.1 The universal soil loss equation (USLE)

USLE is an early empirical model based on relevant influential factors and is widely used in different countries. Wischmeier and Smith (1965, 1978) developed this empirical formula to calculate the rate of soil loss at various geographical scales(Nearing *et al.*, 2017). It is widely used worldwide to quantify soil losses and is frequently integrated with GIS approaches. This model is based on topography, rainfall patterns, land use, soil erodibility, and anti-erosion measures:

$$A_{USLE} = R \times K \times LS \times C \times P$$

where "A is the computed average soil loss (t/ha/year); R is rainfall-runoff erosivity factor measured in mega joules per millimeter per hectare per hour per year (MJ mm ha^{-1} h^{-1} y^{-1}); K is the soil erodibility factor (ton ha h $ha^{-1}MJ^{-1}mm^{-1}$); LS it the topographic factor, L is the slope length (l) factor and S is the slope gradient (s) factor (dimensionless); C is the cropping management factor and P is the supporting conservation practice factor" (Efthimiou and Karavitis, 2016), a dimensionless factor ranging between zero and unity (Djoukbala *et al.*, 2019).

Although erosion depends on sediment being released with flow and fluctuates with runoff and sediment concentration, runoff is not directly taken into account in the USLE model. Although it varies greatly, it has been found that delivery ratios can be utilized to forecast sediment yield from the soil loss equation with high accuracy(Slaughter *et al.*, 2018).

2.4.2 The revised universal soil loss equation (RUSLE)

RUSLE model calculates the typical yearly soil loss (Liu *et al.*, 2025). It is a revised version of USLE which incorporates the "improvement of factors with their level of significance and importance but kept the basis of USLE" (Makara, 2013). "Erosion is a multiplicative function of rainfall-runoff erosivity (R) multiplied by the resistance of the environment, which includes the soil erodibility factor (K), the topography factor (LS), the anti-erosion practices (P) and the vegetation cover factor (C)" (Roose and Noni 2004; Djoukbala *et al.*, 2019). This model is written similarly to the USLE as:

$$A_{RUSLE} = R \times K \times LS \times C \times P$$

RUSLE model is one of many modifications of USLE for more intricate rill and inter-rill erosion scenarios in land uses and conservation planning. In addition to providing an estimate of the degree of erosion, RUSLE is a computing method used for planning, site evaluation, and assisting in the selection of erosion control measures (Tola, 2019). Additionally, it offers data to support the advantages of planned erosion control measures, including the benefits of mulching or installing runoff and diversion trench structures.

2.4.3 The modified universal soil loss equation (MUSLE)

MUSLE model "by (Williams 1975), is a modified version of the USLE model (Wischmeier and Smith, 1965)". In order to forecast soil erosion, this model substituted instantaneous peak flows and the total runoff factor for the rainfall factor (R). As stated by (Djoukbala *et al.*, 2019), "the average soil loss for a flood is a multiplicative function of the volume of the flood (Q in m^3), the peak discharge of the flood (q_p in m^3/s^{-1}), the erodibility of the soil (K), the index slope (S), the slope length (L), the vegetation cover (C) and the cultural practices (P)". The formula given in the form.

$$A_{MUSLE} = 11.8(Q \times q_p)0.56 \times K \times LS \times C \times P$$

MUSLE is an adaptation of the USLE designed to estimate sediment yield from individual storm events rather than annual soil loss (Widiatmika, 2015b). It replaces rainfall erosivity with the function of surface runoff volume and peak runoff rate, making it suitable for event-based erosion predictions. MUSLE is usually used in agriculture but has also been adapted in construction and different environments (Jatav *et al.*, 2018).

2.5 Remote Sensing and Geographic Information Systems

Extended use of USLE/RUSLE to study erosion on larger scales has necessitated the use of geographic information systems and remote sensing (Djoukbala *et al.*, 2019). Since the late 1980s, these instruments have advanced studies on soil erosion and water and soil conservation. Since “all factors can be mapped to determine the values of each factor on erosion per determined spatial unit, which appears in the form of a pixel” (Nearing *et al*, 2017).Thus, RS and GIS are now essential tools for gathering, processing, analyzing, and overlay spatial data that characterizes the watershed environment (Kinnell 2000; Djoukbala *et al.*, 2019). These methods also made it possible to assess soil erosion and its spatial distribution more accurately across wide regions, faster, and at a reasonable cost (Djoukbala *et al.*, 2019).

2.5.1 Remote sensing applications for soil erosion assessment

RS is a geospatial science and study that focuses on identifying and tracking an area's physical features without coming into direct contact with it. “Every object possesses its electromagnetic feature, such as reflectance, emissivity, absorbance, and transmission. Under this specific physical mechanism, RS enables the collection of the target's radiated or reflected signal using remote sensors mounted on different platforms” (Wang *et al.*, 2023).

Thus, RS offers sufficient spatiotemporal data for research in soil science. It can be used to identifying specific soil properties directly or indirectly. In general, the most commonly utilized indirect indicators are vegetation features and land use/cover, whereas the most common direct indicators are mineral composition, organic matter content, surface roughness, and soil water content (Wang *et al.*, 2023). Relevant information on soil erosion, including aspects of erosion, impacted areas, ensuing effects, and environmental factors linked to soil erosion, can be immediately detected using RS data. To determine the degree and severity of erosion, the primary methods are visual interpretation, automatic extraction using classification algorithms, or the use of land surface spectral data (Wang *et al.*, 2025).

By analyzing and mapping satellite data, the vegetation indices have been found to be a rapid and easy feature extraction method for soil erosion (Senanayake and Brennan, 2023). According to several researchers, soil erosion classes might be distinguished by interpreting vegetation cover, and multi-temporal images enable evaluation of its spread. Accordingly, studies reveal that when land degradation occurs, plant cover decreases. For soil erosion vegetation indices, tools like the "Normalized Difference Vegetation Index" have been used to gather data on site-specific attributes such the dominant climate, ecosystem, geography, and physical soil parameters, in addition to plant growth characteristics (Senanayake *et al.*, 2020). One of the most important inputs needed for soil erosion modeling is the digital elevation model (DEM), which can be produced by analyzing remotely sensed spectral data (Senanayake and Brennan, 2023).

2.5.2 Geographic information systems application in soil erosion assessment

GIS is a computer-based application for mapping and examining objects and events on Earth. A wide range of public and private enterprises use GIS to explain events, forecast results, and formulate plans because it combines standard database functions of query and statistical analysis with the special visualization and geographic analysis advantages presented graphically (High Point NC, 2019). Therefore, to properly combat soil erosion, we need dependable measurements and investments in climate and environment monitoring activities. Predictions and assessments of soil erosion and runoff are necessary for the implementation of conservation strategies(Firoozi and Firoozi, 2024) and rehabilitation plans aimed at enhancing long-term sustainable productivity.

2.6 Research Gap Analysis

The study's focus on the specific locality of Phuleng e Nyane in Ha Mantšebo, Maseru, Lesotho addressing a critical geographic gap in soil erosion research. While there is extensive research on soil erosion in Lesotho at watershed scale, detailed investigations targeting this particular and smaller area are scarce. Most existing studies tend to address larger catchments, Lesotho highlands or the country as a whole rather than localized sites where unique combinations of soil properties, topography, and land cover affect erosion processes differently (Majara, 2005; Makara, 2013; Zijl *et.al*, 2013). Hence, this research provides valuable site-specific insight that is currently underrepresented in the scientific literature.

The Universal Soil Loss Equation (USLE) has been widely used in Southern Africa and Lesotho for estimating soil losses. However, many studies focus on singular aspects such as vegetation cover or rainfall erosivity without simultaneously considering how soil condition (such as texture, organic matter content, and structure), topography (including slope length and steepness), and soil cover interact at a fine scale. The combined influence of these parameters is crucial for accurate erosion assessment and for devising effective soil conservation strategies. This research’s comprehensive assessment strengthens the predictive power and practical relevance of erosion modelling for local land management.

Most soil erosion assessment studies predominantly rely on the Universal Soil Loss Equation (USLE) integrated with Geographic Information Systems (GIS) to spatially model erosion risk over landscapes. This approach effectively manipulates USLE factors (R, K, LS, C, and P) derived from spatial datasets to evaluate erosion rates at large scales (Sestras *et al.*, 2023; Medjani *et al.*, 2023; López-García *et al.*, 2020). While GIS-USLE models provide valuable spatial visualization of erosion-prone areas and support land management decisions, they often depend on empirical estimations, remote sensing indices, and assumptions about local conditions (Benavidez *et al.*, 2018).

Contrarily, this study employs an experimental design and laboratory analysis to directly measure soil erosion parameters under controlled conditions. Such an approach enables detailed, empirical insights into soil detachment and transport processes influenced by variables like rainfall intensity and slope, which are generalized in most GIS-based USLE modelling (Sestras *et al.*, 2023; Benavidez *et al.*, 2018). Therefore, the research gap exists in the limited integration of laboratory or field experimental soil erosion data with widely used GIS-USLE predictive models. By filling this gap through empirical data collection, this study aims to enhance the accuracy and reliability of erosion assessments, particularly where spatial datasets are limited or coarse in resolution (López-García *et al.*, 2020; Medjani *et al.*, 2023).

The application of geospatial technologies, including GIS and remote sensing, to support soil erosion modelling has gained momentum globally. In Lesotho, while there are some pioneering efforts, the use of these technologies for detailed risk mapping and dynamic prediction at local scales such as Phuleng e Nyane is limited. For example, Makara (2013) assess the spatial and temporal soil loss in and out of Lesotho using RUSLE model and GIS and Majara (2005), focus on understanding land degradation in Lesotho using satellite imagery to monitor changes in land cover, attributing to degradation due to overgrazing, population expansion and deforestation. This thesis's development of a soil loss prediction model proposes an innovative use of such tools to improve erosion monitoring and future scenario analysis, addressing a notable methodological gap in erosion research within the country.

Erosion impacts along the topo-sequence profoundly affect soil redistribution, nutrient cycling, and land degradation patterns, which in turn influence farming productivity and conservation planning (Omokaro, 2023). For instance, upper slopes may experience more intense soil detachment and transport, while deposition zones lower down might accumulate eroded materials. Despite this significance, many soil erosion studies in Lesotho have not sufficiently mapped or modelled these toposequential variations, often treating sloped areas as homogeneous units.

Topo-sequence analysis fills a critical knowledge gap by clarifying how slope position modulates erosion characteristics and helps develop erosion control measures tailored by slope zones. This method provides valuable insights into spatial variation in soil quality, nutrient distribution, and erosion susceptibility driven by slope gradient and position. For example, the study in Tula, Gombe State, Nigeria, demonstrated notable differences in soil physical and chemical properties along the toposequence, with lower slopes generally showing higher organic content, fertility, and soil quality compared to upper and middle slopes where erosion effects were more pronounced (Jimoh *et al.*, 2022). Given Lesotho's mountainous terrain where slope gradients vary sharply and land-use practices interact with natural processes to drive spatial erosion heterogeneity. Investigating topo-sequence patterns also supports enhanced USLE modelling by refining slope length and steepness factors and integrating spatially explicit soil and vegetation cover data. As a result, this study represents a targeted advancement in understanding landscape-scale erosion dynamics in Lesotho’s complex terrain.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The methodology used to assess soil erosion along two different farming practices comprising a combination of cropland and long-term fallow land is presented in this chapter. The study also focuses on four distinct topo-sequence positions, summit, shoulder, back-slope and toe-slope, which represents key geomorphic units influencing erosion processes as shown in figure 2.1. The methodology integrates field-based data collection, soil sampling and erosion assessments techniques tailored to capture spatial variability in soil loss across these slope positions (Šarapatka *et al.*, 2024).

3.2 Description of the Study Area

The research was carried out at Ha ‘Mantšebo Phuleng-e-Nyane in the upper reach of the Fika-le-Mohala stream sub-catchment located within Latitude -29.48333° S, Longitude 27.51667° E at an elevation of 1657.49 m above sea level. The sub-catchment is situated south of the Moshoeshoe I International Airport southern perimeter line and northeast Ha Thamae village on the foot of the Qeme Plateau at Ha Mantšebo. The area typically receives an average of 83.86 millimeters of precipitation daily over 115.4 rainy days annually (Weather and Climate, 2025). Over the years, the place has been subjected to continuous cultivation with farmers typically growing cereal crop sequences of maize, sorghum, and wheat mixed with livestock husbandry of large stock especially cattle and small stock e.g., sheep and goats. In addition, grasses found at this area included but not limited to, nut grass (*Cyperus rotundus*), creeping woodsorrel (*Oxalis corniculata*), purple lovegrass (*Eragrostis spectabilis*), bermuda grass (*Cynodont dactylon*), dallis grass (*Paspalum dilatatum*) and beardless rabbit’s-foot grass (*Polypogon viridis*). This study area is typically situated on rolling sloppy terrain consisting of two different land use types namely; cropland and more than three years of long term-fallow (grasslands). The study area is shown in Figure *2*.

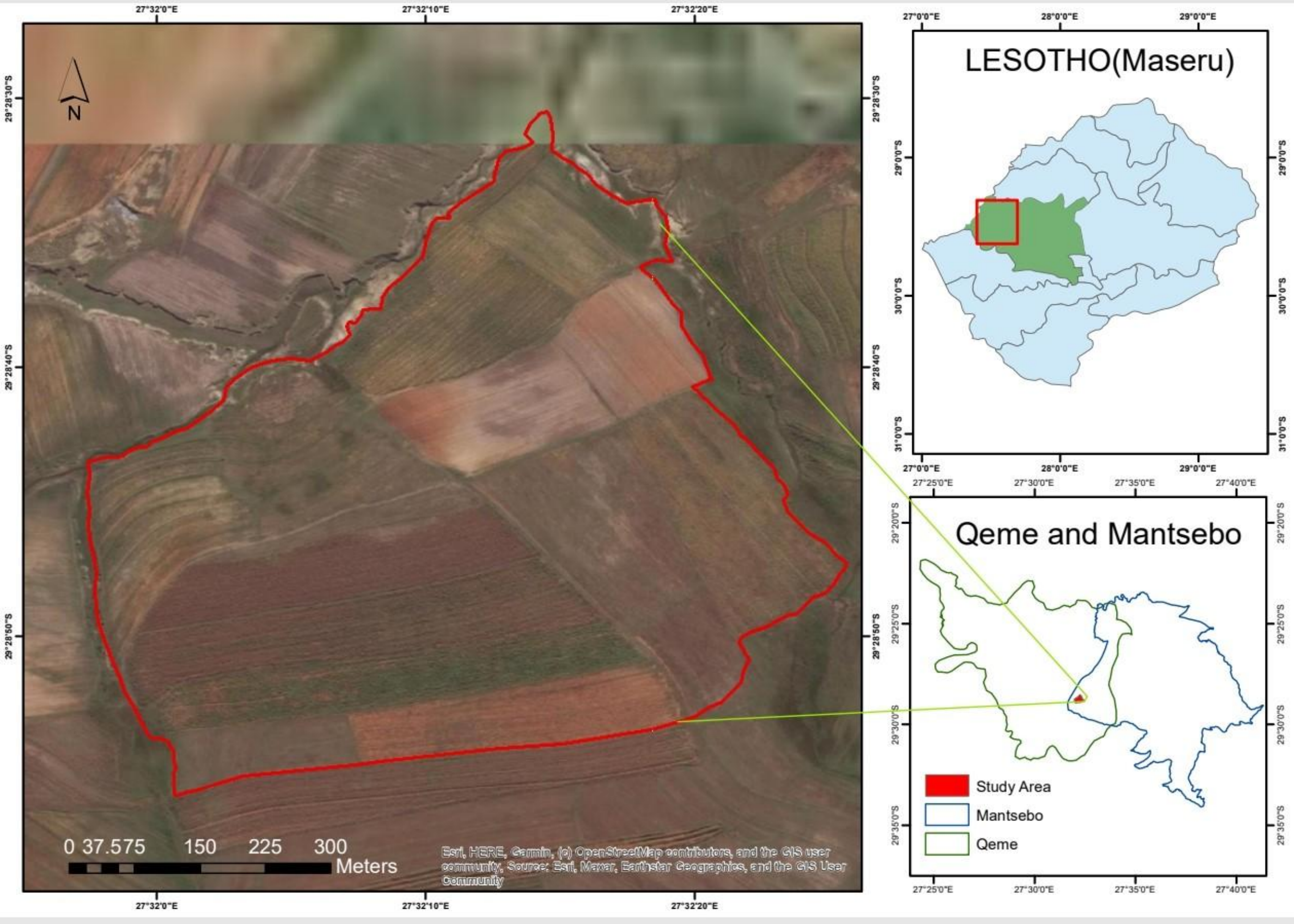

Figure 2: The Map showing the study area at the boundary confluence Qeme and Mantšebo in Maseru district, Lesotho.

3.3 Experimental Design

In this study, a randomized complete block design (RCBD) in split plot arrangement was employed to assess soil erosion across the two land uses (Alam and Maiti, 2025). The main plot consists of the two farming systems i.e. cropland and long-term fallow land with two replicates, representing the primary treatment factor. Within each main plot, the subplot factor was the topo-sequence position comprising four levels: summit, shoulder, back-slope and toe-slope (Figure *3* and Figure *4*). This arrangement allows for efficient evaluation of the interactions between farming systems and slope position on soil erosion processes.

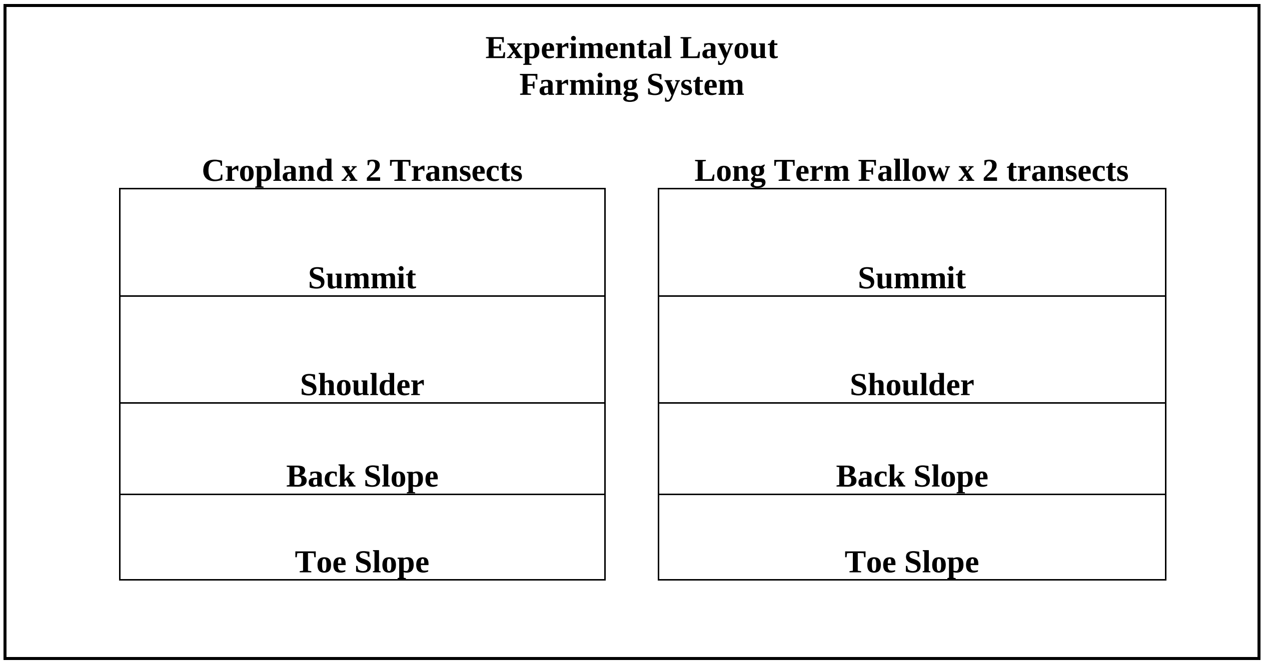

Figure 3: Field layout showing the experimental design.

The study was conceptualized on the landscape as a RCBD in split plot arrangement to optimize field efficiency and data reliability and allowing a systematic observation of erosion along continuous slope gradients. The comparison between cultivated and fallow plots captures the influence of land use on soil detachment and sediment transport. Lastly, combining quantitative soil data with topographic and land use information, the methodology aims to provide a comprehensive assessment of erosion patterns along the four geomorphic positions along the topo-sequence, supporting the identification of erosion hotspots and informing sustainable land management strategies. Figure *4* shows the land use type, topo-sequence and the transect for the sampling locations.

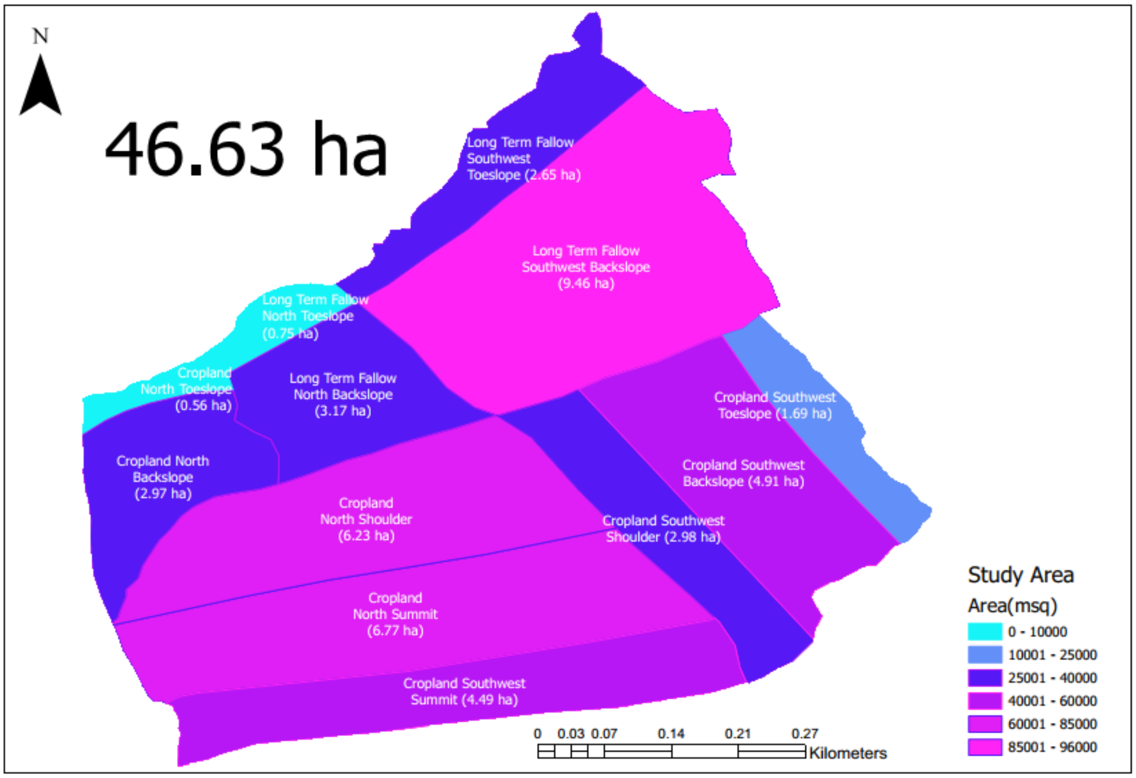

Figure 4: Depiction of the study areas showing the land use type, topo-sequence and the transects.

3.4 Designation of the Sampling Locations

First, the watershed was divided into two transects (north and south-west) each having both a cropland and a long-term fallow. The watershed was divided into twelve sub-watersheds with each sub-watershed described by the land use type and its topographic position along the topographic sequence summit, shoulder, back-slope and the toe-slope. In each sub-watershed, ten sampling points were randomly selected and samples composited to produce three replicates. Three undisturbed core soil samples were also taken from each sampling location. The coordinates (longitude and latitude) of each sampling points were taken using GPS app on android phone. The georeferenced points were used on the Google map to generate the map of the study area. A digital elevation map (DEM) in ArcGIS software was used to determine the land use land cover (LULC) of the area. The slope length of the watershed was measured from the highest elevation to the lowest least for each slope position on each transect and the slope steepness was determined using google earth.

3.5 Soil Sampling Procedure

Soil samples (disturbed and undisturbed) were collected from the designated sampling points. The samples were collected within 30 cm depth. About a kilogram of disturbed samples, were collected with a handheld soil auger and were put in plastic bags and labeled appropriately with identification of the sampling location and land use type. The undisturbed samples were collected with the aid of core samplers, flat wood, hammer, hand trowel and sharp knife (Osinuga and Oyegoke, 2019). The sampler was driven into the soil by placing the flat wood across without fully covering to be able to see the level of the soil. The wood was gently hit by a harmer until the sampler has reached the desired depth. A spade was used to remove the sampler from the soil, and a sharp knife was used to scrape extra soil from the sampler until the soil flushes with the edge.

The undisturbed soil samples were also placed in appropriately labelled plastic sip lock bags. The samples were thereafter transported to the Soil Science Laboratory at the National University of Lesotho for analyses. The soil samples were air dried and crushed to pass a 2 mm sieve for particle size analysis using hydrometer method (Kebede and Hunduma, 2020). Organic matter content was determined by Walkley-Black Titration method whereby organic carbon is measured via oxidation and correction and conversion factor (1.724) was used to estimate the organic matter. The soil granular size was determined following Corey (2018) procedure and the size was classified, according to Huffman *et al.* (2013) into structure codes [1: fine granular (1 – 2 mm); 2: granular (2 – 3 mm); 3: medium to coarse (3 – 5 mm) and 4: blocky, platy or massive (construction sites)]. The undisturbed samples were tested for permeability, using the constant-head permeameter (Imtiaz, 2021); and bulk density (BD), using the core sampler procedure according to (Blake and Hartge, 1986). The result of the permeability was also classified, according to Huffman *et al.* (2013) into profile permeability [1: rapid (sandy to gravel); 2: moderate to rapid (sandy loam); 3: moderate (loam, silt loam); 5: slow (high clay content) and 6: very slow (high clay content, poor aggregation)”.

Secondary rainfall data was collected from the Lesotho Meteorological Services (meteorological station at Moshoeshoe 1 International Airport which is about 2.12 km away from the study area) since there is no facility in place to collect the primary rainfall data on the site. The topographic slope length (SL) was measured by taking the linear distance from the highest elevation to the lowest elevation. The elevation at the highest and lowest points were measured and recorded using a GPS app (GPS Coordinate pro) on android phone. This data was used to calculate the slope steepness for topographic factor. The land use land cover of the study area was determined on the field and on google earth to compare the use over the years (Tola, 2019).

3.6 Data Analysis

The various factors of the USLE were evaluated according to the respective equation as detailed below. The values of appropriate parameters as obtained from the field measurement and laboratory analyses were used in the equations.

3.6.1 Evaluation of the rainfall erosivity index

The rainfall erosivity index (R) was evaluated according to the equation 3.1 of Arnoldus (1977) after correcting the unit and conversion errors (Arnoldus, 1980; Chen *et al.*, 2023; Khodja, 2025). This method is suitably used where rainfall intensities are not available as in case of the current study.

$$R = \sum_{i=1}^{12} 17.02 \times 10^{\left(1.5 log_{10}\left(\frac{{P_i}^2}{P}\right) - 0.8188\right)} \qquad 3.1$$

Where R is the “rainfall erosivity index (MJ mm ha^{-1} h^{-1} yr^{-1}) P_i is the monthly precipitation (mm) and P is the annual precipitation (mm)”.

3.6.2 Determination of the soil erodibility factor (K)

The soil erodibility factor (K) factor in the USLE was evaluated for the study area according to the equation 3.2 (Wischmeier and Smith, 1978; Huffman *et al.*, 2013; Gupta *et al.*, 2023)

$$K = 2.8 \times 10^{-7} M^{1.14}(12 - a) + 4.3 \times 10^{-3}(b - 2) + 3.3 \times 10^{-3}(c - 3) \qquad 3.2$$

Where, K is the soil erodibility factor, (Mg MJ^{-1} $h^{-1}mm^{-1}$ ha h^{1}); M is the textural factor given as:

$$M = (\%silt + \%very\ fine\ sand) * (100 - \%clay) \qquad 3.3$$

a = soil organic matter content, %; b = the soil structure code structure codes “[1: fine granular (1 – 2 mm); 2: granular (2 – 3 mm); 3: medium to coarse (3 – 5 mm) and 4: blocky, platy or massive (construction sites)]”; c = the profile permeability class according to the Table *1*.

Table 1: Permeability class for various soil textures and saturated hydraulic conductivity

Permeability class	Textural Class	Saturated hydraulic conductivity, mm hr^{-1}
1 (fast and very fast)	Sand	> 61.0
2 (moderate fast)	Loamy sand, Sandy loam	20.3 – 61.0
3 (moderate)	Loam, Silty loam	5.1 – 20.3
4 (moderate low)	Sandy clay loam, Clay loam	2.0 – 5.1
5 (low)	Silty clay loam, Sand clay	1.0 – 2.0
6 (very low)	Silty clay, Clay	< 1.0

(Source: Panagos *et al.*, 2014)

3.6.3 Evaluation of the topographic factors

The topographic length factor, L for each topo-sequence on cropland and long-term fallow land was determined according to the equation 3.4.

$$L = \left(\frac{l}{22}\right)^{x} \qquad 3.4$$

Where

l is the slope length (m)

x is an arbitrary value that depends on s

= 0.3 for s < 4%, = 0.4 for s = 4%, = 0.5 for s > 4%

s is the field slope steepness in degrees

The field slope steepness factor S was evaluated according to the equation 3.5

$$S = \frac{(0.43+0.3s+0.043s^2)}{6.574} \qquad 3.5$$

3.6.4 Evaluation of the crop and conservation management factors

The crop management factor, C (degree of cover) was obtained from relevant Table (Table *2*), following the results of the LULC obtained from the GIS while the conservation management factor P was taken to be 1 according to Huffman *et al.* (2013).

3.6.5 Computation of the soil loss (A)

The soil losses in cropland and long-term fallow were evaluated according to equation 3.6 and 3.7, respectively.

$$A_{CL_i} = R_{CL_i} \times K_{CL_i} \times LS_{CL_i} \times C_{CL_i} \times P_{CL_i} \qquad 3.6$$

Whereby; A_{CL_i}= soil erosion under crop land, R, K, LS, C and P are the erosion factors for cropland for a given topographic position.

$$A_{FL_i} = R_{Fl_i} \times K_{FL_i} \times LS_{FL_i} \times C_{FL_i} \times P_{FL_i} \qquad 3.7$$

Whereby A_{FL_i} = soil loss under long term fallow, R, K, LS, C and P are the erosion factors for long-term fallow land for a given topographic position.

The total soil loss from the field was calculated by summing the soil losses from the land use types for the two transects of north and southwest using the equation below

$$A_{total} = \sum_{i=1}^{4}[(CL_i + FL_i)_N + (CL_i + FL_i)_{SW}] \qquad 3.8$$

Where A_{total} is the total soil loss (Mg ha^{-1} yr^{-1}); i is the topo-sequence position; CL is the cropped land; FL is the long-term fallow land; N is the north (transects) and SW is the southwest (transect).

Table 2 :C-factor for different land use land cover

Land use/cover	C-factor
Forest	0.01
Shrub land	0.01
Cultivated land	0.25
Grassland	0.01
Bare land	0.05
Urban built-up areas	0.05
Wetlands	0.01

Source: Miheretu *et al.* (2017)

3.7 Statistical Analysis

Data on soil properties and erodibility were subjected to analysis of variance (ANOVA) following the split-plot design arrangement. Where F-value was significant at 5%, means were separated using Tukey test at 5% level of probability. For this, the statistical software, SISVAR® (Ferreira, 2011), was used (www.dex.ufla.br/~danielff. The step-wise regression and Pearson correlation analyses were performed in SPSS (IBM v. 27).

3.8 Plan for Use of Findings and Results

The research aims to contribute to understanding soil erosion dynamics in Lesotho and inform sustainable and site-specific watershed management practices. The findings and recommendations derived from the research will be shared to benefit the local community through erosion control strategies or policy suggestions for study area.

3.9 Limitations of the Study

Conducting the analysis in a specific area (Phuleng-e-Nyane, Ha Mantšebo) means that the findings might not be universally applicable. The conclusions are limited to this geographical context but may be adopted in similar regions. While USLE is widely used, it has its own constraints. It provides an estimation of soil loss but does not account for sediment deposition or spatial variability in erosion processes. The interpretation of results was influenced by the assumptions made during modeling or data analysis, which can lead to subjective conclusions**.**

3.10 Ethical Considerations

Firstly, the research prioritized environmental responsibility where all activities, such as soil sampling and field surveys, were designed to minimize environmental disturbance. Efforts were made to leave the environment as it was found, preserving biodiversity and the natural landscape.

Additionally, the informed consent for land access was obtained from the local authorities including permission to access privately owned or communal lands. The methodology did not involve any personal or sensitive information from land owners and local authorities.

The findings of the study will be accurately and transparently reported, acknowledging any limitations or uncertainties that might arise during the study to ensure that the study will maintain its credibility and provide a clear foundation for further research.

Thus, the ethical considerations in this study encompassed environmental stewardship, informed consent, community collaboration, research integrity, and benefit sharing. By addressing these aspects proactively, the research will strive to contribute positively not only to the academic community but also to the environment and the local population. This ethical approach will ensure the study’s relevance and sustainability in the long term.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents a comprehensive assessment of soil erosion loss in Phuleng –e-Nyane in Ha Mantšebo using the USLE framework. The analysis draws on both laboratory analysis and field data collection to estimate each USLE factor to provide a robust, site-specific evaluation of erosion. By structurally analyzing the contributions of rainfall patterns, soil properties, topography, land cover, and conservation practices (Tola, 2019), this study aims to identify the primary drivers of soil loss and inform tailored interventions for erosion control for this study area**.**

4.2 Results of USLE Parameters

This section presents results of the USLE parameters calculated in the context of the study.

4.2.1 Rainfall erosivity index, R

The monthly and annual rainfall data of the study area over a period of 40-year (1981 – 2020) is presented on Table A1 of the Appendix. The average monthly rainfall ranged from 12.48 mm in July to a maximum of 128.45 mm in January. The average annual monthly rainfall over the period ranged from a minimum of 33.89 mm in 1992 to a maximum of 90.27 mm in 2006. The R value, according to equation 3.1 is 1256.89 MJ mm ha^{-1} yr^{-1}.

4.2.2 Soil properties and soil erodibility factor, K

The results of the soil properties on the four topo-sequences for the north and southwest transects considered for this study on the cropland and fallow land are presented on Table *4*. The soil erodibility factor K is a function of some physical and hydraulic properties including the bulk density (BD), saturated hydraulic conductivity (Ksat), textural class, organic matter content (OM), etc. (Çerçioğlu *et al.*, 2025).

The results of soil parameters and soil erodibility factor (K) for the two land use types in the north transect is presented on Table *3*. On the cropped land, the clay content, averaged at 20.3%, and ranged from 18.1% at the Toe-slope (TS) to 22.8% at the Summit. The clay content at the TS is significantly lower ($p < 0.05$) than at the other topo-sequence positions. Essentially, the clay content at the Summit (SU), Shoulder (SH) and the Backslope (BS) is statistically the same. However, there is significant difference ($p > 0.05$) in the clay content between BS and TS. In contrast, highest silt content (29.3%) was recorded at TS, while the minimum (24.6%) was recorded at SH. Statistically, there is no difference ($p > 0.05$) in the silt content at the SU, SH and BS.

Table 3 :Average values of soil parameters and erodibility of the two land use types in the north transect.

Slope Position	Clay	Silt	Sand	Texture	SOM	Ksat	BD	Soil structure	K,
	-----------------%--------------			-	%	mm.h^{-1}	Mg m^{-3}	-	$\text{Mg ha}^{-1}\text{ yr}^{-1}$
					Cropland				
Summit	22.8aA	25.9abA	51.3aA	SCL	3.17aA	2.97aA	1.31aA	Fine granular	0.027cA
Shoulder	21.4abA	24.6bA	53.9aA	SCL	3.27aA	1.51bcA	1.38aA	Fine granular	0.030bA
Back slope	18.8abA	27.3abA	53.9aB	SL	3.11aA	2.39abA	1.39aA	Granular	0.029bcA
Toe slope	18.1bA	29.3aA	52.6aA	SL	3.33aA	0.66cA	1.39aA	Medium to coarse	0.035aB
Mean	**20.3**	**26.8**	**52.9**		**3.22**	**1.88**	**1.37**		**0.030**
					Long time Fallow				
Summit	22.8aA	25.9bA	51.3bA	SCL	3.17aA	2.97aA	1.31aA	Fine granular	0.027cA
Shoulder	21.4aA	24.6bA	53.9bA	SCL	3.27aA	1.51bA	1.38aA	Fine granular	0.030bA
Back slope	10.7cB	22.0bB	67.3aA	SL	3.48aA	1.9abA	1.31aA	Granular	0.029bcA
Toe slope	16.8bA	31.5aA	51.9bA	SL	3.35aA	1.01bA	1.22aB	Medium to coarse	0.038aA
Mean	**17.9**	**26.0**	**56.1**		**3.32**	**1.85**	**1.31**		**0.031**
F x Slope ($p<0.05$)	0.016	0.140	0.011		0.698	0.803	0.514		0.351

SOM: soil organic matter; Ksat: saturated hydraulic conductivity; BD: bulk density; K: soil erodibility factor; F x Slope: land use x slope position. Average values in a column followed by different lower-case letters differed significantly among slope positions in a given land use at 5% level of probability by Tukey test. Average values in a column followed by different upper-case letters differed significantly between the two land use types in a given slope position at 5% level of probability by Tukey test

For sand content soil organic matter (SOM) and bulk density (BD), there is no significant difference ($p > 0.05$) in the values for all topo-sequence positions. However, the numerical order is sand: SH = BS > TS > SU; SOM: TS >SH > SU >BS; and BD: BS = TS >SH > SU. On both the cropped land and long-term fallow, the soil texture and soil structure are the same on the corresponding topo-sequence. For example, the soil textural class and soil structure on the SU and SH on both cropped land and long-term fallow are sandy clay loam and fine granular, respectively. The Ksat ranged from 0.66 mm h^{-1} at TS to 2.97 mm h^{-1} at SU with an average of 1.88 mm h^{-1}. The Ksat values at TS and SH are statistically the same ($p > 0.05$), and lower than the values at SU and BS ($p < 0.05$). The order of variation in Ksat on the cropped land is: SU > BS >SH >TS. The values of the soil erodibility factor, K vary from 0.02 Mg ha^{-1} yr^{-1} at SU to 0.035 Mg ha^{-1} yr^{-1} at the TS, with an average of 0.03 Mg ha^{-1} yr^{-1} for the entire cropped land on the north transect. The K value at TS is significantly ($p < 0.05$) higher than others. K at TS is about 129%, 116% and 121% times the K at SU, SH and BS.

On the long-term fallow land, there is no significant difference ($p > 0.05$) in most of the parameters when compared with the cropped land, except for sand content that is significantly ($p < 0.05$) higher at BS on the cropped land, and clay, silt and BD that are significantly ($p < 0.05$) lower at, BS, and TS, respectively on long term fallow land. For the southwest transect, the soil parameter and K factor are presented on **Error! Reference source not found.**. On the cropped land, the clay content at TS (22.8%) is significantly ($p < 0.05$) lower, being about 0.79, 0.83 and 0.82 as much as the clay content in SU, SH and BS, respectively. However, the sand content at TS is significantly higher, being 115%, 122% and 122% times the value at SU, SH and BH, respectively. The soil texture is the same at all the topo-sequence positions, while the soil structure varied from fine granular at SU to granular at the TS. Other parameters, including K are not significantly ($p > 0.05$) different among all the topo-sequence positions. On the long-term fallow, the clay content at BS, being 36-46% lower than at other positions on the topo-sequence, is significantly different ($p < 0.05$). The Ksat generally varied along the topo-sequence in order SU > SH >TS > BS. Ksat at SU, being 2, 6 and 7 times the value at SH, BS and

Table 4: Average values of soil parameters and erodibility of the two land uses on the southwest transect.

Slope Position	Clay	Silt	Sand	Texture	SOM	Ksat	BD	Soil structure	K,
	-----------------%--------------			-	%	$mm.h^{-1}$	$Mg\ m^{-3}$	-	$Mg\ ha^{-1}\ yr^{-1}$
	Cropland								
Summit	28.8aA	22.6aA	48.6bA	SCL	2.86aA	1.43aB	1.36aA	Fine granular	0.0279aA
Shoulder	27.4aA	26.6aA	46.0bB	SCL	2.93aA	1.49aA	1.40aA	Fine to coarse	0.0291aA
Back slope	27.7aA	26.6aA	46.0bB	SCL	2.83aA	2.04aA	1.41aA	Fine granular	0.0282aA
Toe slope	22.8bA	21.3aB	55.9aA	SCL	2.78aA	1.91aA	1.21aB	Granular	0.0285aA
Mean	**26.7**	**24.3**	**49.1**		**2.85**	**1.72**	**1.35**		**0.0284**
Slope position	Long term Fallow								
Summit	22.8aB	25.9aA	51.2aA	SCL	3.17aA	2.97aA	1.31aA	Fine granular	0.0273aA
Shoulder	21.4aB	24.6aA	54.0aA	SCL	3.27aA	1.49bA	1.38aA	Fine granular	0.0271aA
Back slope	14.7bB	30.7aA	54.6aA	SL	3.15aA	0.40cB	1.47aA	Granular	0.0303aA
Toe slope	21.4aA	28.0aA	50.6aB	L	3.05aA	0.49cB	1.52aA	Granular	0.0295aA
Mean	**20.1**	**27.3**	**52.6**		**3.2**	**1.3**	**1.4**		**0.0286**
F x Slope ($p<0.05$)	0.016	0.140	0.011		0.698	0.803	0.514		0.542

SOM: soil organic matter; Ksat: saturated hydraulic conductivity; BD: bulk density; K: soil erodibility factor; Fx Slope: land use x slope position; SCL: sandy clay loam; SL: sandy loam; L: loam. Average values in a column followed by different lower-case letters differed significantly among slope positions in a given land use at 5% level of probability by Tukey test. Average values in a column followed by different upper-case letters differed significantly between the two land use types in a given slope position at 5% level of probability by Tukey test.

TS, respectively, is significantly higher ($p < 0.05$). The soil texture is the same (sandy clay loam) at SU and SH; sandy loam at BS, loam at TS. The texture is fine granular at SU and SH, while it is granular at BS and TS. Other parameters and K are not significantly different.

Comparing the cropped land and long-term fallow, the clay contents at SU, SH and BS on the cropped land is significantly higher than at the corresponding positions on the long-term fallow by 21%, 22% and 47%, respectively. The silt content at the TS of the cropped land is significantly lower by about 24% compared with the TS of the long-term fallow land. The sand contents at SH and BS on the cropped land are significantly lower ($p < 0.05$) than at the respective corresponding positions on the long-term fallow land by 15 and 16%, respectively. A significant difference exists between the sand content at TS, the content on cropped land being about 110% times that on the long-term fallow. The Ksat at BS and TS on long-term fallow, being about 20% and 26% times the Ksat at BS and TS on the cropped land, respectively, are significantly lower. The Ksat at the SU on the cropped land is significantly lower than that at the SU of the long-term fallow by about 52%. Other parameters, including K are not statistically different between the cropped land and the long-term fallow.

4.2.3 Topographic factor, LS

The two components of LS, slope length (L) and slope steepness (S) were measured for each transect along the slope positions and calculated according to equations 3.4 and 3.5 respectively. While the slope length was different for each position on each transect, the slope steepness was found to be 0.89 for all. The topographic factor, LS of the study area, with respect to the topo-sequence and transects on the cropland and the fallow land are presented on table 5 below. The LS factor on the north transects ranged between 0.09 at TS to 0.22 at SU and BS on the cropped land, and between 0.10 at TS to 0.24 at BS on the long-term fallow. For the southwest transects, the LS factor ranged between 0.13 at the TS on cropland, while it varied from 0.11 at the TS to 0.22 at the SU on the long-term fallow.

4.2.4. The crop management (land cover) factor, C

The LULC obtained from the GIS result indicated that the land use types in the study area are cultivated land and grassland (fallow). According to Miheretu *et al.* (2017), the crop management factor, C for cultivated land and fallow land are 0.25 and 0.01, respectively (Table *2*).

4.2.5 Conservation practice factor, P

The studied area is generally terraced. The P-factor, according to Huffman *et al.* (2013), is likely to be the least reliable of all the USLE factors, as the impacts of conservation practices vary with climate, soils, vegetation, and topography of the field, contoured rows, and terrace channels. Based on the above, the worst scenario of P = 1 is often used. Thus, our conservation practice, P is taken as unity.

4.3 Evaluation of Soil Loss on the Field

The soil loss on the cropland is about 20 times the soil loss on the long-term fallow. The order of soil loss on the cropped land for the two transects is BS > SU > SH > TS. However, the soil loss on the BS for cropped land in the north transect is 104%, 115% and 200% times the soil loss at SU, SH and TS, respectively, while in the southwest transect, the soil loss on the BS is for cropped land is 126%, 149% and 246% times the soil loss at SU, SH and TS, respectively. For the long-term fallow, the soil loss in the north transect is in order BS > SU > SH > TS. The soil loss at BS is 113%, 129% and 180% time the soil loss at SU, SH and TS, respectively. similar trend is observed on the southwest transect. However, the soil loss at the BS is 150%, 200% and 300% times the soil loss at SU, SH and TS, respectively.

Table 5: Quantity of soil loss(A) from the field.

Soil loss for the North Transects							
Land use	Topo-sequence	R-factor (t/ha/yr)	K-factor (t/ha/yr)	LS-factor	C-factor	P-factor	Soil Loss (Mg/ha/yr)
Cropland	Summit	1256.89	0.03	0.22	0.25	1.00	1.89
	Shoulder	1256.89	0.03	0.18	0.25	1.00	1.72
	Back-slope	1256.89	0.03	0.22	0.25	1.00	1.98
	Toe-slope	1256.89	0.04	0.09	0.25	1.00	0.99
	Total						**6.58**
Long Term Fallow	Summit	1256.89	0.03	0.22	0.01	1.00	0.08
	Shoulder	1256.89	0.03	0.18	0.01	1.00	0.07
	Back-slope	1256.89	0.03	0.24	0.01	1.00	0.09
	Toe-slope	1256.89	0.04	0.10	0.01	1.00	0.05
	Total						**0.29**

Soil loss for the Southwest Transects							
Land use	Topo-sequence						
Cropland	Summit	1256.89	0.03	0.16	0.25	1.00	1.40
	Shoulder	1256.89	0.03	0.13	0.25	1.00	1.19
	Back-slope	1256.89	0.03	0.20	0.25	1.00	1.77
	Toe-slope	1256.89	0.03	0.08	0.25	1.00	0.72
	Total						**5.08**
Long Term Fallow	Summit	1256.89	0.03	0.22	0.01	1.00	0.08
	Shoulder	1256.89	0.03	0.18	0.01	1.00	0.06
	Back-slope	1256.89	0.03	0.31	0.01	1.00	0.12
	Toe-slope	1256.89	0.03	0.11	0.01	1.00	0.04
	Total						**0.30**

The numbers in bold character are the sum of the soil losses for each land use type on the two transects.

The soil losses from different sections of the field under the two land uses (cropped land and long-term fallow) for the north and southwest transects are presented in Table . The total soil loss from the entire area, according to the equation 3.6 is 12.25 Mg ha^{-1} yr^{-1}, with cropped land contributing about 95.2% of the loss (about 53.7% from the north transect and 41.5% from the southwest transect). The remaining 4.8% was from the long-term fallow land (approximately shared equally among the two transects).

4.4 Relationship between Soil Properties and Erosion Characteristics

The results of correlation analysis between soil loss and the contributing factors are presented on Table . The soil loss (A) exhibits a strong positive relationship with C ($R = 0.92$; $p < 0.01$) and clay content ($R = 0.42$; $p < 0.01$).

Table 6: Pearson correlation between soil loss, soil properties and soil loss factor.

Prop.	A	Clay	Silt	Sand	BD	SOM	Ksat	K	LS	C
A	1	0.415**	-0.087	-0.311*	0.048	-0.211	0.196	-0.165	-0.010	0.916**
Clay		1	-0.213	-0.747**	0.029	-0.386**	0.228	-0.681**	-0.264	0.467**
Silt			1	-0.490**	0.240	0.238	-0.201	0.563**	0.016	-0.155
Sand				1	-0.190	0.182	-0.067	0.225	0.225	-0.311*
BD					1	0.148	-0.411**	0.080	0.159	-0.027
SOM						1	0.049	0.097	0.119	-0.276

Ksat	1	-0.075	0.249	0.098
K		1	0.489**	-0.376**
LS			1	-0.287*
C				1

C: land use factor; LS is the topographic factor; K is the soil erodibility factor, Ksat is the saturated hydraulic conductivity, SOM is the soil organic matter; BD is the bulk density; A is the soil loss and N is the number of samples. *means significant at $p < 0.05$; ** means significant at $p < 0.01$.

However, an inverse relationship exists between A and sand content ($R = -0.31$; $p < 0.05$). The relationship of A with other factors, both direct and inverse, are not significant ($p > 0.05$). The soil clay content exhibits a significant negative relationship ($R =0.68$; $p < 0.01$) with the soil erodibility factor (K), while it (clay content) displays a significant positive relationship ($R = 0.47$; $p < 0.01$) with the C factor. A significant positive relationship ($R = 0.56$; $p < 0.01$) exists between the soil silt content and K. On the other hand, sand content of the spoil has a significant inverse relationship ($R =0.31$; $p < 0.05$) with C factor. A strong positive relationship ($R = 0.49$; $p < 0.01$) exists between the K and LS factor, while a strong negative relationship ($R = 0.38$; $p < 0.01$) exists between K and C. A significant inverse relationship ($R = 0.29$; $p < 0.05$) is exhibited between LS and C.

4.5 Development of Localized Predictive Model

The regression analysis between A and the influencing factors are presented in Table . The regression analysis revealed that C is the most important factor influencing soil loss in the study area, accounting for about 84% of the soil loss in the watershed. Topographic factor LS is the second most influential factor, explaining about 70% of the soil loss in the watershed. The regression equation is given as:

$$A = -7.33 + 6.25C + 1.73LS + 105.76K + 0.074Clay + 0.309SOM + 0.028Sand \qquad 4.1$$

Where A is the soil loss (Mg ha^{-1} yr^{-1}), C is the land use factor, LS is the topographic factor, K is the soil erodibility factor, clay is the percentage clay content of the soil, SOM is the soil organic matter (%) and silt is the percentage silt content of the soil.

Table 7: Step-wise regression of soil loss versus soil properties and soil loss factors for the watershed.

Soil Loss vs	Model	R^2	ΔR^2	Reg (p-value)	R^2 change (p-value)
C	A = 0.014 + 5.77C	0.839	0.839	< 0.001	0.000
C, LS	A = -0.656 + 6.27C + 3.41LS	0.909	0.070	< 0.001	0.000
C, LS, K	A = -1.375 + 6.45C + 2.86LS + 28.40K	0.917	0.008	< 0.001	0.045
C, LS, K, Clay	A = -2.53 + 6.20C + 2.62LS + 54.27K + 0.024Clay	0.927	0.011	< 0.001	0.015
C, LS, K, Clay, SOM	A = -3.60 + 6.27C + 2.47LS + 64.39K + 0.033Clay + 0.195SOM	0.935	0.007	< 0.001	0.038
*C, LS, K, Clay, SOM, Sand	A = -7.33 + 6.25C + 1.73LS + 105.76K + 0.074Clay + 0.309SOM + 0.028Sand	0.942	0.007	< 0.001	0.032

C: land use factor; LS is the topographic factor; K is soil erodibility factor; SOM is the soil organic matter

*Overall regression model

C is the most important factor contributing to soil loss in the watershed, followed by LS and K. This is also reflected in the correlation result

CHAPTER FIVE

DISCUSSION OF THE RESULTS

5.1 Introduction

In this chapter, I seek to interpret and explain the significance of the results presented in the previous chapter and consider the potential limitations, explain the observed patterns. Drawing comparisons with previous studies in Lesotho and elsewhere, this chapter aims to provide the understanding of the driving forces for soil erosion in this area.

5.2 Discussion for USLE Parameters

The Universal Soil Loss Equation (USLE) is a widely used empirical model for estimating soil erosion, primarily due to its simplicity and minimal data requirements (Hadush *et al.*, 2025). The significance of USLE parameters lies in their ability to quantify various factors contributing to soil erosion, enabling effective land management and conservation strategies. Each parameter in the USLE model represents a specific aspect of the erosion process, and their accurate estimation is crucial for reliable predictions. The parameters include rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practices (P). These parameters collectively help in assessing the potential soil loss in a given area, guiding stakeholders in implementing appropriate soil conservation measures (SaThierbach *et al.*, 2015).

5.2.1 Rainfall erosivity

The R factor represents the effect of rainfall intensity and amount on soil erosion. It is a critical parameter as precipitation is the primary driver of soil erosion by water. Rainfall erosivity combines the energy of rainfall and the maximum continuous 30-minute intensity during a rainfall event, which directly impacts soil particle detachment and transport via runoff (Nazuhan *et al.*, 2018). One significant local climate component that contributes to the creation of splash, sheet, and rill erosion is the rainfall erosivity factor. Based on the quantity and intensity of rainfall, whether from a single storm or a sequence of storms, this component illustrates how rainfall intensity affects soil erosion (Koirala *et al.*, 2019).

In this study, the calculated R factor was 1256.89 MJ mm $\text{ha}^{-1}\ \text{yr}^{-1}$ (Equation 3.1). According to

(Okorafor *et al.*, 2017), rainfall erosivity values below 2452 MJ mm ha^{-1} yr^{-1} are considered low, therefore this study area falls under low erosivity category. Furthermore, the standard criteria of rainfall erosivity indicate that Lesotho's rains are comparatively less erosive (Society *et al.*, 1994). However, their study shows that standard measures of erosivity are of little use for the rainfall regime of Lesotho as it would produce inaccurate results if used in equations for erosion prediction. This means that the rainfall while capable of causing soil erosion, has relatively low erosive potential compared to area with higher R-values. Despite this classification, it is important to recognize that even low erosivity rainfall can contribute to significant soil loss when combined with vulnerable land use practices.

5.2.2 Soil erodibility and soil properties

The K factor quantifies the susceptibility of soil particles to detachment and transport by rainfall and runoff. It is influenced by soil properties such as texture, structure, organic matter content, and permeability (Nsanzimana *et al.*, 2024). Accurate estimation of the K factor is essential for predicting soil loss, and modifications in its evaluation using satellite imagery and ground observations have shown improved estimates (Khire and Mundhe, 2010). It depends on the soil properties and varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content (Tabita *et al.*, 2024). In this study soil erodibility does not account for soil loss given that the soil has high sand content (45% to 67%) making the soils less erodible, soil organic matter is greater than 2% ranging from 2.78 on cropland to 3.48 on long-term fallow, soil structure with most of the soils being fine granular and high permeability. The soil organic matter reduces compaction by promoting soil aggregation and increasing porosity (Teklu, 2005).

In this study, the mean K-factor was 0.0284 and 0.0286 Mg ha^{-1} yr^{-1} in cropland and long-term fallow, Table 4. However, there was significant different between the difference in the K-factor in the North transect, with the toeslope and summit having the highest and lowest values, respectively along the topographic positions regardless of farming system regime. Increased soil erosion due to a higher soil erodibility factor has significant environmental implications on terrestrial ecosystems. The K-factor, indicates the susceptibility of soil to erosion by water and wind. A higher soil erodibility factor suggests that the soil is more prone to being detached and transported by erosive forces, leading to various environmental challenges including land degradation and agricultural productivity.

The North transect had the highest but not significant SOM in the TS but not the case for southwest transect in this case, toe-slope suggest that overland flow and surface runoff have transported these soil nutrients down the slope (Jimoh *et al.*, 2022). Sand content was significantly highest in BS in the North transect under Long-time fallow while it was significantly highest in TS in the southwest transect under Cropland. Though these results show irregularities between the two land uses, the higher sand content at the lower positions of the toposequence can only be explained by increased force of rainfall hitting the ground as sandy soil are highly permeable and larger and heavier requiring more energy to detach and transport (Sharwan, 202200. Although the sand particles do not bind well together, the high permeability allows water to filtrate rather than runoff, reducing erosion. According to (Panagos *et al.*, 2014) K-factor data is a guide for applying better conservation practices e.g., increase or preserve soil organic carbon in areas prone to high levels of soil erosion risk or adaption of soil management strategies at areas of high risk.

5.2.3 Topographic factor, LS

The LS factor accounts for the influence of topography on erosion rates and combines the effects of slope length and slope steepness (Moisa, 2020), which affect the velocity and volume of runoff. Given that the slope steepness was 0.089 (section 4.2.3), this means the study area have a moderate slope with only 8.9% incline (FA0, 2006). The slope factor was found to be the second most influencing factor of soil loss in the study area. Normally, there is a positive and strong correlation between the slope gradient and soil loss (Hacısaliho *et al.*, 2010). The LS factor quantifies how much more (or less) soil is eroded from a particular slope compared to a standard reference slope, which is defined as 22.13 meters long with a 9% gradient interpreted as follows: When the LS factor = 1, the slope has the same erosion potential as the standard reference slope; When the LS factor < 1, the slope is less erosive than the standard slope; and a LS factor > 1 indicates a slope that is more erosive than the standard slope. In this study, the LS factor values are less than unity (Range = 0.09 to 0.24) regardless of farming system regimes hence indicative of a low erosion potential (Tables 3 and 4). Generally, increases in slope length and slope steepness can create higher overland flow and higher erosion. Moreover, the overall soil loss is considerably more sensitive to changes in slope steepness than to changes in slope length (Belasri and Lakhouili, 2016).

5.2.4 The crop management (land cover) factor, C

The impact of farming and management techniques on soil erosion rates is reflected in the C factor. It varies with land use and vegetation cover and influences the protection of soil from raindrop impact and surface runoff hence it is a crucial parameter that quantifies the influence of different cropping and management practices on the rate of soil erosion within a given landscape (Kobusinge *et al.*, 2023). In the context of the USLE, the C factor represents the ratio of soil loss from land under specific management to a similar soil loss from bare and continuously tilled land, which is considered the worst-case scenario for erosion. Values for the C factor range from 0-1 indicating excellent ground cover and minimal erosion when the C-factor approaches zero to unity which signifies bare, tilled soil with maximum erosion risk. In this study, cultivated and long-term fallow lands were compared and the contrast between these land uses offers valuable insight into the impact of crop management on soil erosion. Cultivated land typically exhibits higher C factor values due to frequent tillage operations and the removal of crop residues, both of which reduce the protective ground cover and leave the soil more exposed to erosive forces such as rainfall and wind. The risk of soil erosion is particularly pronounced during periods when the land is left bare, such as after harvest and before the establishment of the next crop when there is minimal canopy cover to shield the soil surface. Conversely, fallow lands are left uncultivated for a period, permitting natural vegetation to regenerate. The effectiveness of fallow land in reducing soil erosion is largely dependent on the duration and the amount of ground cover available all year round (Kim and Julien, 2006).

5.2.5 Conservation practice factor, P

The P factor represents the impact of practices that reduce the amount and rate of water runoff, such as contouring, strip cropping, and terracing and adjustments in the P parameter evaluation have shown a close association with sedimentation, indicating its importance in soil conservation planning (Khire & Mundhe, 2010). Soil loss from a field with the specified conservation strategy compared to one without conservation is thus defined by the P factor. In the absence of conservation measures the value of P is unity (Tabita *et al.*, 2024), which represents the worst case scenario for the occurrence of soil erosion. However, the P factor is known to be one of the more uncertain parameters because it depends heavily on specific local practices, their implementation quality, and spatial variability, which are often difficult to measure or generalize reliably. For this study, setting P - factor at unity was a practical decision to avoid introducing potentially large errors from poorly estimated conservation effects prioritizing model simplicity and transparency.

5.3 Evaluation of Soil Loss on the Field

According to section 4.3 there is high soil loss on cropland compared to on the long-term fallow, this was expected as the soil on the cropland experiences soil disturbance and have reduced cover that increase the erosion risk while long term fallow maintains protective vegetation and more stable soil structure (Mishra *et al.*, 2025). In addition, the soil loss on the crop land and long-term fallow followed the order, BS>SU>SH>TS, this is because the backslope is steeper, water follow faster with greater erosive power, the summit and shoulder are milder allowing for more infiltration and less runoff. The toeslope is where the slope eases and water velocity decreases causing sediment to settle and accumulate and reduce soil loss (Cheng *et al.*, 2010; Vanini and Amini, 2017)

The total soil loss from study area was calculated at 12.25 Mg ha^{-1} yr^{-1}. This means that on average 12250 kg of soil are lost from each hectare of the study area every year due to erosion processes. The quantity will vary somewhat subject to climate, parent material, topography, and biotic factors influencing soil variation (Takoutsing *et al.*, 2017). In this this study, a large proportion of the local soil variation can be attributed to land use and topography rather than climate and parent material (Hu *et al.*, 2019; Jimoh *et al.*, 2022). Soil erosion severity classification is important in providing a practical framework to interpret USLE outputs beyond raw soil loss values by linking erosion rates to meaningful risk categories that can inform decision making and conservation strategies. The study area was found to have “moderate soil loss”, class V (12 to 25 Mg ha^{-1} yr^{-1}) based on the estimated annual soil loss rates of USLE (Miheretu and Yimer, 2017) and the severity of classes (Bewket and Teferi, 2009).

5.4 Development of Localized Predictive Model

In this study, a localized predictive soil loss model utilizing the USLE was developed. This model is able to capture the influence of the local conditions such as topography, soil type, rainfall patterns vegetable cover and land use that a general model would not accurately reflect. It offers significant potential applications and benefits in soil conservation, agricultural management, and environmental sustainability. This model, in conjunction with Geographic Information Systems (GIS), provide detailed insights into soil erosion patterns and rates. By enabling precise identification of erosion-prone areas, it facilitates targeted conservation efforts, optimize agricultural practices, and contribute to broader environmental sustainability goals.   This model is crucial for effective land and environmental management because it accounts to the fact that soil erosion is not a one-size-fits all.

CHAPTER SIX

CONCLUSION AND RECOMMENDARION

6.1 Conclusions

Based on the findings of this study, the following conclusions were drawn

(i) The erosivity (R = 1256.89 MJ mm ha^{-1} yr^{-1}) of the studied area is low, indicating that the rainfall pattern of the area is not a principal contributor to soil erosion.

(ii) Higher clay content in the soil of the studied area indicates higher soil loss while higher sand content means lower soil loss. Other soil parameters, including silt content, have no significant influence on soil loss.

(iii) The impact of topography on soil loss in the study area is not high.

(iv) The land use pattern in the study area is the major factor that is responsible for soil loss.

(v) A localized predictive model, as a function of factors influencing soil loss in the studied area was developed.

6.2 Recommendations

The following recommendations are suggested in attempts to curb soil loss in the study area

(i) Appropriate land use patterns that conform with erosion control within the study area should be adopted

(ii) A continuous monitoring of the soil loss within the study area should be carried out for at least some years. This will help to improve the predicting model developed and will thus becomes useful for long-term soil loss prediction for the studied area.

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APPENDIX

Appendix A

Monthly rainfall data for the study area from 1981 t 2020 years

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	AVG.
1981	220	129	94	51	39	27	0	75	6	31	92	113	875	73
1982	52	94	53	183	11	22	43	0	47	128	102	51	785	65
1983	50	84	39	49	27	26	77	4	12	97	151	92	708	59
1984	85	57	70	25	93	3	10	52	5	72	122	38	632	53
1985	107	106	62	45	7	37	0	1	5	103	147	110	730	61
1986	93	72	87	38	0	35	1	64	26	133	162	63	774	64
1987	29	88	66	95	2	7	19	28	110	40	74	110	667	56
1988	27	169	138	109	26	21	9	12	63	134	74	157	940	78
1989	70	202	73	44	64	33	10	7	5	35	97	43	681	57
1990	203	78	165	101	9	40	10	27	2	13	21	90	757	63
1991	226	168	146	7	1	23	1	2	63	151	78	119	984	82
1992	37	45	45	15	0	0	0	50	2	67	116	29	407	34
1993	113	122	82	55	12	2	0	34	12	149	73	69	725	60
1994	194	88	107	26	0	0	7	0	0	12	52	49	535	45
1995	131	65	129	22	21	0	0	4	11	82	64	138	667	56
1996	104	148	119	66	18	0	40	9	16	83	157	82	842	70
1997	171	55	169	58	83	23	24	21	7	36	73	83	805	67
1998	94	118	189	28	26	0	8	2	20	82	153	123	842	70
1999	117	60	83	23	55	3	0	2	5	97	26	232	702	58
2000	119	110	122	84	37	7	3	4	64	78	104	115	847	71
2001	64	86	110	137	62	23	6	46	15	142	184	180	1054	88
2002	225	73	64	50	81	11	4	94	32	48	36	92	812	68
2003	102	110	93	16	13	0	3	18	37	31	50	52	525	44
2004	105	103	144	50	3	15	5	16	37	51	52	86	668	56
2005	182	135	128	81	32	2	0	24	8	79	98	37	806	67
2006	251	206	131	75	26	2	2	88	8	80	124	91	1083	90
2007	63	37	27	53	6	26	1	6	61	139	129	128	675	56
2008	120	88	105	40	39	53	9	4	3	24	154	94	731	61
2009	206	168	65	25	26	34	21	2	4	172	85	66	873	73
2010	188	88	69	84	15	31	0	0	1	73	145	234	930	78
2011	319	99	133	123	92	24	20	4	2	9	22	145	992	83
2012	67	122	102	45	1	67	36	9	25	54	91	221	841	70
2013	120	33	80	64	3	2	0	9	1	54	101	137	605	50
2014	114	169	121	37	5	0	0	16	3	35	234	113	848	71
2015	174	58	149	25	11	36	13	2	4	28	44	7	552	46
2016	126	60	95	101	75	13	92	20	17	39	104	49	791	66
2017	141	208	32	56	13	8	7	2	4	72	74	164	779	65

2018	104	126	238	87	54	2	16	49	10	30	18	40	773	64
2019	59	161	136	141	16	2	0	2	11	1	42	134	705	59
2020	165	143	98	92	1	0	4	2	16	61	119	126	828	69
TOT	5138	4331	4156	2506	1103	661	499	812	778	2847	3844	4099	30775	2565
AVG.	128	108	104	63	28	17	12	20	19	71	96	102	769	64